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# ANALYSIS OF PROCESS PARAMETERS IN MILLING OF GLASS FIBRE REINFORCED PLASTIC COMPOSITES

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## ABSTRACT

*Milling is one of the most important machining processes in manufacturing parts made out of FRPs. Milling is a very versatile process capable of producing simple two dimensional flat shapes to complex three dimensional interlaced surface configurations, in which a rotating, multi-tooth cutter removes material while traveling along various axes with respect to the work piece. However, unlike the milling of metals which is characterized by high material removal rates, milling of FRPs is conducted at much lower scale. The reason for this is that FRP components are largely made near net shape and any subsequent milling is limited mainly to de-burring and trimming as well as to achieving contour shape accuracy. Milling composite materials are significantly affected by the tendency of these materials to delaminate under the action of machining forces, cutting force, feed force and depth force respectively.*

*Quality surface milling of Glass Fibre reinforced Plastic materials present variety of issues, such milling is one of the foremost oftentimes used material removal processes in machining of FRPs to produce a well-defined surface finish and has surface delamination related to the characteristics of the material and therefore the cutting parameters used. The surface quality and dimensional precision greatly have an effect on the elements throughout their useful life, especially in cases wherever the elements come in contact with different elements or materials. Optimization of machining parameters is a necessary step in machining. This project presents a new approach for optimizing the machining parameters on end milling of glass-fibre reinforced plastic composites. Optimization of machining parameters was done by Taguchi method in milling experiments were conducted for Glass fibre reinforced plastic composite plates using solid carbide end mills with various helix angles. The parameters of machining such as, Fibre orientation angle, spindle speed, feed rate and helix angle are*

*optimized by multi-response concerns particularly surface roughness and machining force the optimum levels of parameters have been investigated by using Taguchi method.*

**Key words:** ANOVA; Design of experiments; GFRP composites; Machining; Taguchi.

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# 1. INTRODUCTION

Composites are one of the most widely used materials because of their adaptability to different situations and the relative case of combination with other materials to serve specific purposes and exhibit desirable properties. Glass fibre reinforced plastics. Composite is considered to be an economic alternative to various heavy exotic materials. Glass-fibre-reinforced plastic is an advanced polymeric matrix composite material, the use of these composites in engineering applications such as automotive, aircraft etc. have been increased considerably in recent years due to their light weight, high modulus, high specific strength, superior corrosion resistance, high fracture toughness and resistance to chemical and microbiological attacks (Praveen Raj and Elaya Perumal, 2010). Glass fibre reinforced plastic composite materials are extremely abrasive when machined. Thus the selection of the cutting tool and the cutting parameters is very important in the machining process. Fibre-glass is simply a composite consisting of glass fibres, either continuous or discontinuous, contained within a polymer matrix. The machining of composite is different from the conventional machining of metal due to the composite's anisotropic and non-homogeneous nature (Ramkumar et al., 2004).

Milling is one of the most important machining processes in manufacturing parts made out of Fibre reinforced plastic. Milling is a very versatile process capable of producing simple two dimensional flat shapes to complex three dimensional interlaced surface configurations, in which a rotating, multi-tooth cutter removes material while traveling along various axes with respect to the work piece. However, unlike the milling of metals which is characterized by high material removal rates, milling of FRPs is conducted at much lower scale. The reason for this is that FRP components are largely made near net shape and any subsequent milling is limited mainly to de-burring and trimming as well as to achieving contour shape accuracy. Milling composite materials are significantly affected by the tendency of these materials to delaminate under the action of machining forces, cutting force, feed force and depth of cut respectively. Taguchi's method has been used widely in engineering analysis. It provides a simple efficient and systematic approach to optimize design for performance quality and cost. These techniques consist of a plan of experiments with the objective of acquiring data in a controlled way, executing these experiments, in order to obtain information about the behavior of a given process. The main trust over Taguchi technique is the use of parameter design which is an engineering method for product or process design that focuses on determining the parameters settings producing the best levels of quality.

# 2. ANALYSIS OF VARIANCE (ANOVA)

Analysis of variance is a mathematical technique which is based on the least square approach. The purpose of ANOVA is to investigate the process parameters which significantly affect the performance characteristics. As per this technique, if the calculated value of the $F$ ratio of the developed model does not exceed the standard tabulated value of $F$ ratio for a desired level of confidence, then the model is considered to be adequate within the confidence limit. The variance ratio, denoted by $F$ in ANOVA tables, is the ratio of the mean square due to a factor and the error mean square. In robust design, $F$ ratio can be used for qualitative understanding of the relative factor

effects. A high value of $F$ means that the effect of that factor is large compared to the error variance. So, the larger the value of $F$, the more important is that factor in influencing the process response

## 3. THE EXPERIMENTAL WORK

This investigation deals with machining Glass fibre reinforced plastic Work piece use a milling tool. The experiments were conducted on a precision milling machine. Mitutoyo surface roughness tester (SJ-201), profilimeter (Mitutoyo Corporation, Japan) was used to measured surface roughness of the milled holes. The delamination factor was measured by using tool maker's microscope. Shows the experimental setup in order to validate the inferred fuzzy models, a set of pilot experiments were performed with the following different machining conditions.

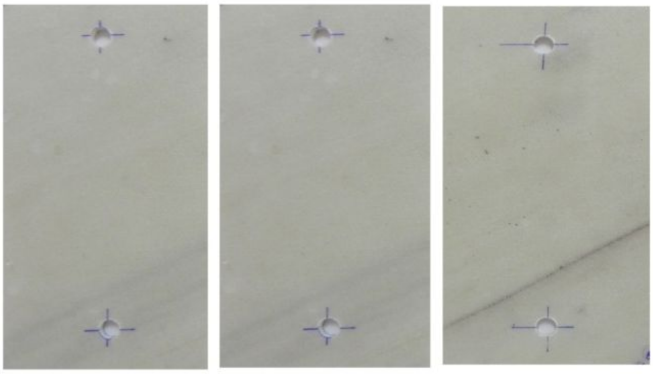


**Figure 1** GFRP composite plates before machining

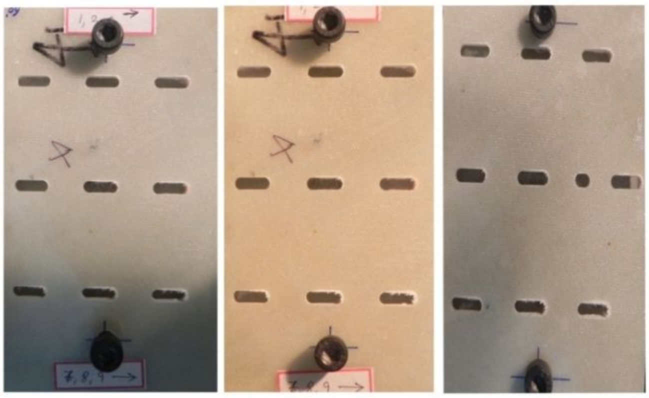


**Figure 2** GFRP composite plates after machining

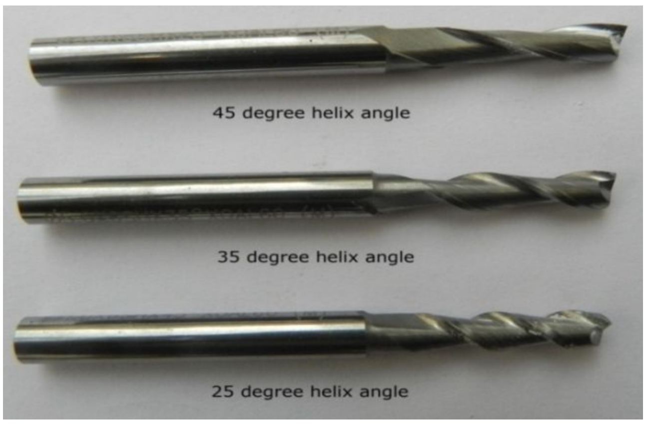



**Figure 3** Solid carbide end mill with different helix angles

**Figure 4** Fixation of composite plate by using clamps in the machining centre

**Table 1** Specification of the CNC milling machine

| Type of machine | Vertical machine centre |
|---|---|
| Make | Hartford, Taiwan |
| Table size | 800 x 400 mm |
| Spindle motor power | 7.5 KW |
| Spindle speed | 50-8000 rpm |
| Feed | 1-7000 mm/min |
| X axis | 500 mm |
| Y axis | 400 mm |
| Z axis | 400 mm |
| Accuracy (Positioning) | ± 0.005/300 mm |

**Table 2** Process control parameters and their levels

| | | | Levels | | |
|---|---|---|---|---|---|
| **Process parameters** | **Units** | **Notations** | **1** | **2** | **3** |
| FOA | Deg. | Φ | 15 | 60 | 105 |
| HA | Deg. | θ | 25 | 35 | 45 |
| SS | RPM | N | 200 | 400 | 600 |
| FR | Mm/rev | f | 0.04 | 0.08 | 0.12 |

Conducted an experimental investigation to determine the effect of the cutting conditions on the surface roughness and Machining Force during machining of Glass fibre reinforced plastic Work piece. The investigation demonstration that the effect of the cutting conditions on the surface roughness, and machining force was significant. The surface roughness and Machining force are measured after each cut. The obtained data analyzed and the influence of the cutting parameters on the machining variable is determined in the form of rules to Design of experiments. Taguchi method was developed to describe the relationship between the machining condition and surface roughness and Machining force. This section uses the developed DOE to study influence of the process parameters on the surface roughness and Machining force within the machining conditions.

In this investigation, the surface roughness values and Machining force are obtained by a machining process with a full factorial i.e. a three factor three level design was used to study the effects of the four process parameters Θ, N and f on surface roughness (µm) and Machining force. Helix angle is significant in surface roughness, and Machining force.

## 4. EXPERIMENTAL DESIGN

The Taguchi design was selected to find out the relationships between independent variables, Surface roughness, Machining force and Delamination factor. The independent variables were Fibre

orientation angle, Helix angle, Spindle Speed and feed rate, the experiments were carried out to analyze the influence of cutting parameters on tool surface roughness, machining force and delamination factors for machining hardened GFRP steels. Cutting parameters were selected keeping in mind that the hard milling operation was generally used as a finishing operation as an alternative to grinding.

The three fibre orientation angles (Φ) $15^0$, $60^0$, and $105\ ^0$. Three helix angles (θ) $25^0$, $35^0$, and $45^0$. Three spindle speeds (N) 2000 rpm, 4000 rpm, and 6000 rpm. Three feed rates (*f*) 0.04 mm/rev, 0.08 mm/rev, and 0.12 mm/rev were selected. Details of experimental design, control factors and their levels, results for surface roughness are shown in Table2, results for machining forces are shown in table, results for Machining force are shown in table 4 . These tables show that the experimental plan had three levels. A standard Taguchi experimental plan with notation L27 was chosen. The rows in the L27 orthogonal array used in the experiment corresponded to each trial and the columns contained the factors to be studied. The first column consisted of fibre orientation angle, the second contained the helix angle and the third column contained spindle speed consecutive column consisted of the feed rate. The experiments were conducted twice for each row of the orthogonal array to circumvent the possible errors in the experimental study. In the Taguchi method, the experimental results are transformed into a signal-to-noise (S/N) ratio. This method recommends the use of S/N ratio to measure the quality characteristics deviating from the desired values. To obtain optimal testing parameters, the-lower-the-better quality characteristic for machining the steels was taken due to measurement of the surface roughness. To obtain optimal testing parameters, the-smaller-the-better quality characteristic for machining the steels was taken due to measurement of the surface roughness and Machining force. The S/N ratio for each level of testing parameters was computed based on the S/N analysis. This design was sufficient to investigate the three ain effects. With S/N ratio analysis, the optimal combination of the testing parameters could be determined.

**Table 3** Experimental design and results for surface roughness and their S/N ratios

| TCN | FOA($^0$) | HA($^0$) | SS(RPM) | FR(mm/rev) | SR µm | S/N |
|---|---|---|---|---|---|---|
| 1 | 15 | 25 | 2000 | 0.04 | 0.91 | 0.81 |
| 2 | 15 | 25 | 4000 | 0.08 | 0.85 | 1.41 |
| 3 | 15 | 25 | 6000 | 0.12 | 0.95 | 0.44 |
| 4 | 15 | 35 | 2000 | 0.08 | 1.10 | -0.82 |
| 5 | 15 | 35 | 4000 | 0.12 | 1.18 | -1.43 |
| 6 | 15 | 35 | 6000 | 0.04 | 0.92 | 0.72 |
| 7 | 15 | 45 | 2000 | 0.12 | 1.59 | -4.02 |
| 8 | 15 | 45 | 4000 | 0.04 | 1.32 | -2.41 |
| 9 | 15 | 45 | 6000 | 0.08 | 1.30 | -0.66 |
| 10 | 60 | 25 | 2000 | 0.04 | 1.08 | -1.93 |
| 11 | 60 | 25 | 4000 | 0.08 | 1.25 | -2.21 |
| 12 | 60 | 25 | 6000 | 0.12 | 1.29 | -4.19 |
| 13 | 60 | 35 | 2000 | 0.08 | 1.62 | -4.55 |
| 14 | 60 | 35 | 4000 | 0.12 | 1.69 | -3.40 |
| 15 | 60 | 35 | 6000 | 0.04 | 1.48 | -5.20 |
| 16 | 60 | 45 | 2000 | 0.12 | 1.82 | -3.97 |
| 17 | 60 | 45 | 4000 | 0.04 | 1.58 | -4.19 |
| 18 | 60 | 45 | 6000 | 0.08 | 1.62 | -2.86 |
| 19 | 105 | 25 | 2000 | 0.04 | 1.39 | -4.29 |
| 20 | 105 | 25 | 4000 | 0.08 | 1.64 | -4.71 |
| 21 | 105 | 25 | 6000 | 0.12 | 1.72 | -5.93 |
| 22 | 105 | 35 | 2000 | 0.08 | 1.98 | -6.36 |
| 23 | 105 | 35 | 4000 | 0.12 | 2.08 | -4.50 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 24 | 105 | 35 | 6000 | 0.04 | 1.68 | -7.88 |
| 25 | 105 | 45 | 2000 | 0.12 | 2.48 | -6.27 |
| 26 | 105 | 45 | 4000 | 0.04 | 2.06 | -6.22 |
| 27 | 105 | 45 | 6000 | 0.08 | 2.12 | -6.52 |

**Table 4** Experimental design and results for Machining force and their S/N ratios

| TCN | FOA($^0$) | HA($^0$) | SS(RPM) | FR(mm/rev) | MF µm | S/N |
|---|---|---|---|---|---|---|
| 1 | 15 | 25 | 2000 | 0.04 | 15.27 | -23.67 |
| 2 | 15 | 25 | 4000 | 0.08 | 20.78 | -23.35 |
| 3 | 15 | 25 | 6000 | 0.12 | 22.79 | -27.15 |
| 4 | 15 | 35 | 2000 | 0.08 | 19.25 | -25.68 |
| 5 | 15 | 35 | 4000 | 0.12 | 21.64 | -26.70 |
| 6 | 15 | 35 | 6000 | 0.04 | 14.21 | -23.05 |
| 7 | 15 | 45 | 2000 | 0.12 | 20.79 | -26.35 |
| 8 | 15 | 45 | 4000 | 0.04 | 13.54 | -22.63 |
| 9 | 15 | 45 | 6000 | 0.08 | 18.15 | -25.17 |
| 10 | 60 | 25 | 2000 | 0.04 | 26.24 | -28.37 |
| 11 | 60 | 25 | 4000 | 0.08 | 28.16 | -28.99 |
| 12 | 60 | 25 | 6000 | 0.12 | 30.14 | -29.58 |
| 13 | 60 | 35 | 2000 | 0.08 | 24.32 | -27.71 |
| 14 | 60 | 35 | 4000 | 0.12 | 31.84 | -30.05 |
| 15 | 60 | 35 | 6000 | 0.04 | 21.19 | -26.52 |
| 16 | 60 | 45 | 2000 | 0.12 | 32.15 | -30.14 |
| 17 | 60 | 45 | 4000 | 0.04 | 20.79 | -26.35 |
| 18 | 60 | 45 | 6000 | 0.08 | 25.62 | -28.17 |
| 19 | 105 | 25 | 2000 | 0.04 | 39.24 | -31.87 |
| 20 | 105 | 25 | 4000 | 0.08 | 37.25 | -31.42 |
| 21 | 105 | 25 | 6000 | 0.12 | 59.61 | -35.50 |
| 22 | 105 | 35 | 2000 | 0.08 | 39.25 | -31.87 |
| 23 | 105 | 35 | 4000 | 0.12 | 41.52 | -32.36 |
| 24 | 105 | 35 | 6000 | 0.04 | 29.72 | -29.46 |
| 25 | 105 | 45 | 2000 | 0.12 | 38.62 | -31.73 |
| 26 | 105 | 45 | 4000 | 0.04 | 29.15 | -29.29 |
| 27 | 105 | 45 | 6000 | 0.08 | 19.26 | -25.69 |

## 5. RESULTS

### 5.1. Analysis of Control Factors for Surface Roughness

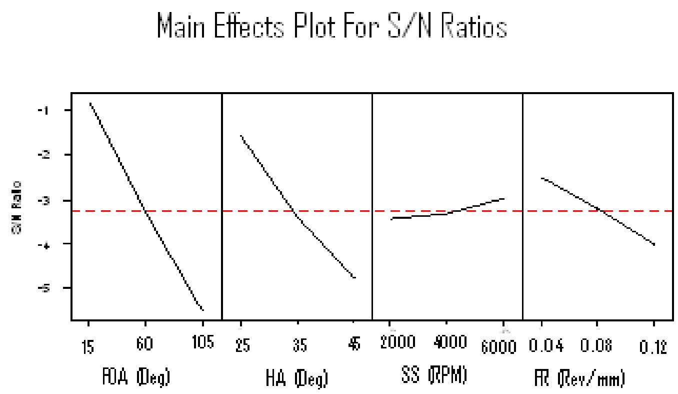
Analysis of the influence of each control factor ($\Phi$, θ, N, and f) on the surface roughness was performed with a signal-to-noise (S/N) response table. The experimental design, results for surface roughness and S/N ratios are shown in Table3. The control factors and their un-coded surface roughness were included in this table. Table3 shows the S/N response table of surface roughness. It indicates the S/N ratio at each level of control factor and how it was changed when settings of each control factor were changed from level 1 to level 2. The influence of interactions between control factors was neglected here. The control factor with the strongest influence was determined by differences value. The higher the difference, the more influential was the control factor.

**Table 5** S/N response table of surface roughness

| Symbol | Control factors | Average s/n ratio (db) | | | | Rank |
|---|---|---|---|---|---|---|
| | | L-1 | L-2 | L-3 | Max-Min | |
| Φ | FOA | -0.84 | -3.37 | -5.48 | 4.62 | 1 |
| θ | HA | -1.55 | -3.38 | -4.75 | 3.19 | 2 |
| N | SS | -3.41 | -3.31 | -2.96 | 0.45 | 4 |
| f | FR | -2.5 | -3.19 | -3.99 | 1.48 | 3 |

It could be seen in Table that the strongest influence was exerted by Fibre orientation angle, followed by Helix angle, Feed rate, and lastly Spindle speed respectively. Since the first level of the surface roughness was about -0.842 db while the third level of the surface roughness was about -5.484 db the difference being the most highest of 4.642 db. It is followed by the Helix angle. The first level of the surface roughness was about -1.556db and third level of the surface roughness was about -4.752 db, the difference being the most highest of 3.196 db which is significant level again. Which is followed by the feed rate The difference between the first level of the surface roughness and third level of the surface roughness was found to be about 1.488 db, The spindle speed showed the least effect on the surface roughness since the difference between the third level and first level were about 0.457 db.

## 5.2. Graph 1: Main Effects Plots on the Surface Roughness




**Graph 1** Main effects Plots on the surface roughness

Graph 1. shows the main effect plots for surface roughness of the work piece for S/N ratios, respectively. The greater is the S/N ratio, the smaller is the variance of the surface roughness around the desired value. Optimal testing conditions of these control factors could be very easily determined from the response graph. The best surface roughness value was at the higher S/N value in the response graph. For main control factors, Graph1 indicates the optimum condition for the tested samples ($\Phi_1$, $\Theta_1$, $N_3$ and f3). Thus, it could be concluded that the best surface finish of work piece can be achieved and their optimal setting of control factors for tested samples are shown in Table6.

**Table 6** Optimum level of control factors for surface roughness

| MCF | SYM | OL | OV |
|---|---|---|---|
| FOA | Φ | 1 | $15^0$ |
| HA | θ | 1 | $25^0$ |
| SS | N | 3 | 6000rpm |
| FR | f | 1 | 0.04mm/rev |

**Table 7** Analysis of variance of surface roughness

| SYM | DOF | SS | MS | F-Cal. | P-dis.(%) |
|---|---|---|---|---|---|
| Φ | 2 | 207.631 | 103.81 | 45.7 | 69.69 |
| θ | 2 | 7.008 | 3.50 | 1.54 | 2.34 |
| N | 2 | 4.115 | 2.05 | 0.91 | 1.38 |
| f | 2 | 38.331 | 19.16 | 8.45 | 12 |
| Error | 18 | 40.836 | 2.26 | | |
| Total | 26 | 297.92 | | | |

## 6. ANALYSIS OF CONTROL FACTORLS FOR MACHINING FORCE

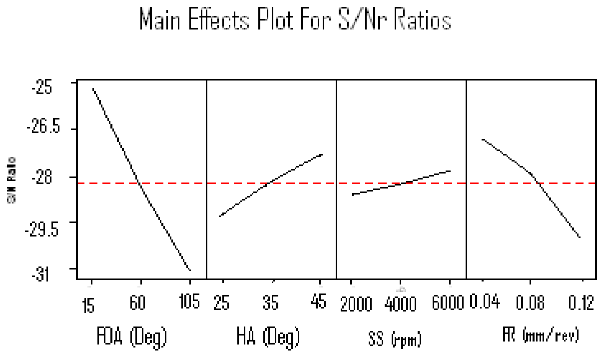
Analysis of the influence of each control factor (*Φ, θ N and f*) on the machining force was performed with a signal-to-noise (S/N) response table. The experimental design, results for Machining force and S/N ratios are shown in Table 4.4. The control factors and their un-coded Machining force values were included in this table. Table 5.4 shows the S/N response table of Machining force. It indicates the S/N ratio at each level of control factor and how it was changed when settings of each control factor were changed from level 1 to level 2. The influence of interactions between control factors was neglected here. The control factor with the strongest influence was determined by differences value. The higher the difference, the more influential was the control factor.

**Table 8** S/N response table of Machining force

| Symbol | Control factors | Average S/N ratio (db) | | | | Rank |
|---|---|---|---|---|---|---|
| | | L-1 | L-2 | L-3 | Max-Min | |
| Φ | FOA | -25.19 | -28.43 | -31.02 | 5.82 | 1 |
| θ | HA | -29.21 | -28.16 | -27.28 | 1.93 | 3 |
| N | SS | -28.60 | -28.24 | -27.81 | 0.79 | 4 |
| F | FR | -26.80 | -27.89 | -29.95 | 3.15 | 2 |

It could be seen in Table8 that the strongest influence was exerted by Fibre orientation angle, followed by the feed rate, Helix angle, lastly Spindle speed respectively. Since the first level of the Fibre orientation angle was about – 25.19 db while the Third level was about – 31.02 db the difference being the most highest of 5.82 db. It is followed by the feed rate. The difference between the first level and third level was found to be about 3.15db, which is significant level again. It is followed by the Helix angle. The difference between the third level and first level was found to be about 1.93 db, which is significant level again, The Spindle speed showed the least effect on the machining force since the difference between the third level and first level were about 0.79 db, which is also significant level again.

### 6.1. Main Effect Plots for Machining Force: S/N ratio (db)




**Graph 2** Main Effects on the Delamination Factor

Graph 2 shows the main effect plots for Machining force of the Machining tool for S/N ratios. The greater is the S/N ratio, the smaller is the variance of the machining force around the desired value. Optimal testing conditions of these control factors could be very easily determined from the response graph. The best machining force value was at the higher S/N value in the response graph. For main control factors indicates the optimum condition for the tested samples ($\Phi_1$, $\theta_3$, $N_3$, and $f_l$). Thus, it could be concluded that the minimum Machining force of the machining tool achieved and their optimal setting of control factors for tested samples are shown in Table 8

**Table 8** Optimum level of control factors for Delamination factor

| MCF | SYM | OL | OV |
|---|---|---|---|
| FOA | Φ | 1 | $15^0$ |
| HA | θ | 3 | $45^0$ |
| SS | N | 3 | 6000rpm |
| FR | f | 1 | 0.04mm/rev |

From the results of control factors, minimum machining force was obtained under cutting conditions of $\Phi= 15^o$, $\theta = 45^o$, N = 600 rpm and f = 0.04 mm/rev when machining GFRP work piece by cutting tool. The experimental work was carried out on the same GFRP work piece using the determined optimal control factors. The machining force was found to be about 10.8 N. Then this value was transferred to the S/N ratio (db), average value of S/N ratio was calculated and it was about -20.67 db. An Orthogonal design, S/N ratio and ANOVA were employed to determine the effective cutting parameters such as *Φ*, θ, N and *f* on the machining force. It was concluded that the hardness of the Fibre orientation angle was found to be the most important parameters on the machining force among control parameters.

## 7. ANALYSIS OF VARIANCE OF MACHINING FORCE

The analysis of variance (ANOVA) was used to investigate which design parameters significantly affect the quality characteristics of the machining force for the milling process. The results of the ANOVA of machining force in machining GFRP work piece shown in Table 5.6. In addition to degree of freedom, mean of squares (MS), sum of squares (SS), *F*-ratio and *P*-values associated with each factor level were presented. This analysis was performed for a confidence level of 90%. The *F* value for each design parameters was calculated. The calculated value of the *F* showed a high influence of fibre orientation angle (Φ) on the machining force since *F*-calculation was equal to 45.76, but the Helix angle(θ), Spindle speed (N) and feed rate (f) had also significant effects on the machining force since *F*-test was equal to 1.54, 0.91 and 8.45, respectively. The last column of the above table

indicated the percentage of each factor contribution (*P*) on the total variation, thus exhibiting the degree of influence on the result. It was important to observe the *P*-values in the table. From the analysis of Table9 the fibre orientation angle ($P \approx 69.699\%$) showed a high significant effect. It was followed by feed ($P \approx 12.86\%$), Helix angle ($P \approx 2.34\%$),), and Spindle speed ($P \approx 1.38\%$) as well.

**Table 9** Results of ANOVA for machining force in machining GFRP

| SYM | DOF | SS | MS | F-Cal. | P-dis.(%) |
|---|---|---|---|---|---|
| Φ | 2 | 207.63 | 103.815 | 45.76 | 69.69 |
| θ | 2 | 7.008 | 3.504 | 1.54 | 2.34 |
| N | 2 | 4.115 | 2.058 | 0.91 | 1.38 |
| f | 2 | 38.331 | 19.166 | 8.45 | 12.86 |
| Error | 18 | 4.836 | 2.269 | - | 13.2 |
| Total | 26 | 297.921 | - | | 100 |

## 8. CONCLUSIONS

The following conclusions could be drawn from results of surface roughness of GFRP work piece.

- The L27 Orthogonal array was adopted to investigate the effects of fibre orientation angle, Helix angle, Spindle speed, and feed rate on the surface roughness. The results showed that the Fibre orientation angle exerted the greatest effect surface roughness, Helix angle, feed rate and, lastly the Spindle speed.
- The estimated S/N ratio using the optimal testing parameter for the surface roughness was calculated. Furthermore, the ANOVA indicated that the fibre orientation angle was high significant but other parameters were also significant on the tool life at 90% confidence level.
- The percentage contributions of fibre orientation angle, Helix angle, Feed rate, and Spindle speed were about 60.88, 28.99, and 6.25 and 0.643 on the surface roughness, respectively.

The following conclusions could be drawn from results of machining force on GFRP work piece.

- The L27 Orthogonal array was adopted to investigate the effects of fibre orientation angle, Helix angle, Spindle speed, and feed rate on the machining force. The results showed that the Fibre orientation angle exerted the greatest effect machining force, feed rate, Helix angle and, lastly the Spindle speed.
- The estimated S/N ratio using the optimal testing parameter for the machining force was calculated. Moreover, the ANOVA indicated that the fibre orientation angle was high significant but other parameters were also significant on the machining force at 90% confidence level.
- The percentage contributions fibre orientation angle, feed rate, Helix angle and Spindle speed were about 66.69 12.86, 2.34 and 1.38 on the Machining force respectively.

Nomenclature

- $\theta$ : Helix angle
- $N$ : Spindle Speed
- $f$ : Feed rate
- $W_{max}$ : Maximum Width of Cut
- $W$ : Width of Cut
- $R_a$ :Surface Roughness
- *FOA* :Fibre orientation angle
- *HA* :Helix angle
- *SS* :Spindle speed
- *FR* :Feed rate

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